Shallow and Deep Current Variability in the Southwestern Japan/East Sea

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Award Number: N000149810246 *and* N0001400WX20337
http://po.gso.uri.edu/dynamics/jes/index.html

LONG-TERM GOALS

We seek to understand the physics of the mesoscale circulation in the Japan/East Sea, with our efforts focusing on the southwestern region where the variability is especially energetic.

OBJECTIVES

(1) To observe the time-varying transports of the branches of the Tsushima Current in the Ulleung Basin. From the observations, we can chart the upper layer circulation and eddies with mesoscale resolution on a daily basis.

(2) To understand the physical coupling between the shallow and deep currents and eddies within this region, where large-amplitude meanders and steep loop formations occur.

(3) To quantify cross-frontal and vertical fluxes associated with mesoscale processes.

APPROACH

For the two years, June-1999 to July-2001, we deployed a two-dimensional array of pressure-gauge-equipped inverted echo sounders (PIES) and deep recording current meters (RCM) in the Ulleung

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2002		**00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Shallow and Deep Current Variability in the Southwestern Japan/East Sea	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Graduate School of Oceanography,University of Rhode Island,,South Ferry Road,,Narragansett,,RI, 02882**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
We seek to understand the physics of the mesoscale circulation in the Japan/East Sea, with our efforts focusing on the southwestern region where the variability is especially energetic.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT	b ABSTRACT	c THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**7**	

Basin. These current meter moorings augmented a set of 4 moorings deployed by the Korean Ocean Research and Development Institute (KORDI, Dr. M.-S. Suk) and an additional mooring installed by the Research Institute for Applied Mechanics at Kyushu University (RIAM, Dr. J.-H. Yoon). The region spanned was roughly a 250-km square between Korea and Japan.

Our method of Gravest Empirical Mode (GEM) analysis of historical hydrographic data from the Ulleung Basin, combined with NRL's Modular Ocean Data Assimilation System (MODAS) analysis, has been applied to interpret the acoustic echo time data to estimate full profiles of temperature *T*, specific volume anomaly δ, and other variables. The deep current measurements have now been used to level the pressure measurements for geostrophic calculations. These combined instruments (23 PIESs and 17 RCMs) provide two-year time series of dynamic height, vertical shear, and deep current fields, which has enabled us to map the upper and deep absolute current and temperature structure on a daily basis. We have also assembled datasets of atmospheric pressure, wind stress, and coastal tide gauge data from the surrounding region.

WORK COMPLETED

In last year's annual report we described the successful recovery record for the deployed RCMs and PIESs and collection of CTD data for verification on a July 2001 cruise aboard R/V Melville. We noted that seven of the PIES sites had been dragged short distances during their moored period, and their pressure and travel time records exhibited simultaneous jumps associated with depth changes (of a few centimeters to tens of meters) in both upward and downward directions. The jumps occurred at locations (1000-1400m depth sites) and during seasons of heaviest deep crab fishing activity. The data clean-up has required us to identify and account for the depth jumps, which was a more difficult and time-consuming job than we normally encounter.

At this time, a year after instrument recovery, the cleaned calibrated data sets have been shared with our international collaborators and with other ONR/JES PI's. We have presented five papers at three international meetings (cited below), and we have submitted to Deep-Sea Research three initial papers on our findings (summarized below) for the special issue on the Japan/East Sea. Work proceeds on additional follow-up papers.

RESULTS

We have generated from our observations, three-dimensional (x,y,z) time-series of synoptically mapped current and temperature fields in the Ulleung Basin. Mitchell et al. [2002] report that during the two-year measurement period, at least five quasi-stable upper flow patterns were found (Figure 1). The changes between flow patterns during the first year (6/99-6/00) correspond with changes in the volume transport through the Korea Strait (KS), while the changes in patterns during the second year (6/00-6/01) do not. The mean temperature of upper waters in the basin changes interannually and is correlated with the KS transport, with much colder mean temperature during the second year when the KS transport reached a multi-year low. We suggest a new framework for describing the flow patterns within the Ulleung Basin based on four features that recur and persist in various time intervals: the East Korean Warm Current, the Ulleung Warm Eddy, the Offshore Branch, and a newly described Dok Cold Eddy. The Dok Cold Eddy (DCE), about 60 km in diameter, typically forms southwest of Dok Island when the Subpolar Front loops southward between Ulleung and Dok Islands and sheds an eddy. The DCE is highly variable in space and time, and it tends to propagate westward toward the coast of

Korea, where it merges with cold waters from the north. Three such merger events immediately precede the disappearance of the East Korean Warm Current, which then remains absent between June and November 2000. The Offshore Branch forms by branching in the KS and is present throughout the two-year observation period.

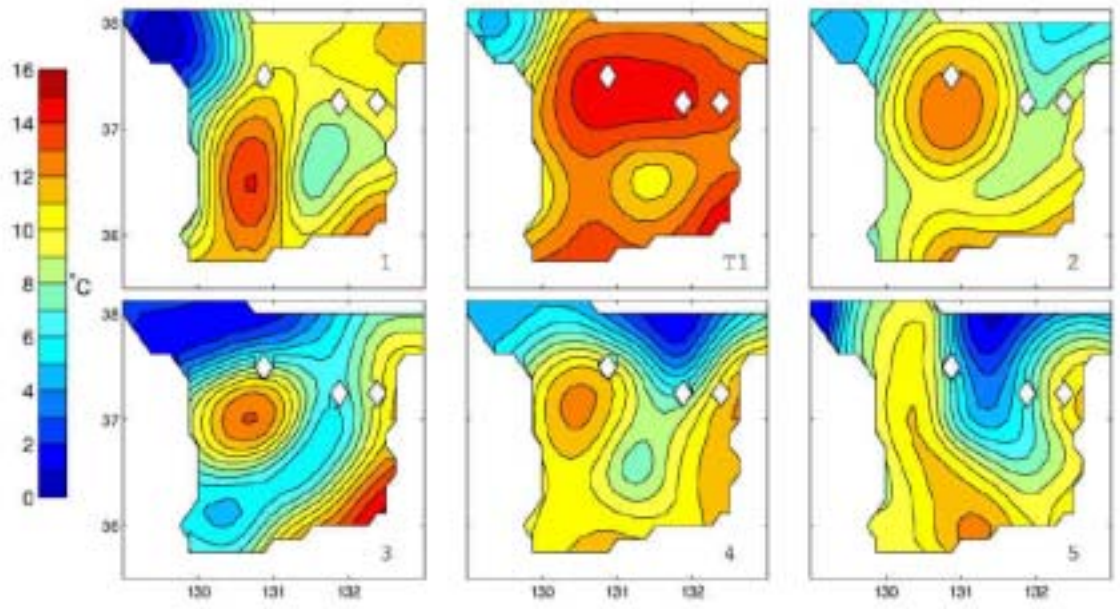

Figure 1. Flow patterns in Ulleung Basin, averaged over specified time intervals, as indicated by temperature at 100 m, with colorbar temperature scale at left. [1: Aug 13 – Sept 30, 1999, Ulleung Warm Eddy and Dok Cold Eddy; T1: Nov 11 – Dec 31, 1999, warming basin transition; 2: Feb 2 – June 10, 2000, Ulleung Eddy, East Korean Warm Current and Offshore Branch prevalent; 3: June 17 – Nov 5, 2000, small UWE, absent EKWC, basin cold; 4: Nov 29 – Mar 21, 2001, UWE, EKWC, OB, intrusion of Subpolar Front; 5: Apr 16 – Jun 21, 2001, large meander, strong intrusion of SPF.]

Teague et al. [2002] report on the deep circulation observed by sixteen deep current meters and twenty-three bottom pressure gauges in the Ulleung Basin (UB). The pressure records were detided and a basin-wide oscillation of the free surface was subtracted from the records, in order to work with the residual geostrophic pressures. Rms eddy currents and pressures ranged from about 1 to 6 cm/s and 0.01 to 0.02 dbar, at different locations, with horizontal correlation scales of about 40 km, and integral time scales that range from about 5 to 20 days. The deep circulation in the UB at seasonal to annual time scales is clearly cyclonic with additional cyclonic and anticyclonic cells that occur on sub-basin scales. Over the Korea Plateau a northward deep outflow is observed that suggests an anticyclonic circulation pattern further to the north. There is mainly southwestward inflow through the channel between Ulleung and Dok Islands, with a hint of outflow along the channel's southeastern side. The annual average deep currents are remarkably similar for the two years (Figure 2), being only slightly weaker in the second year despite a 40% decrease in the Korea Strait inflow and the above-summarized qualitative changes that occurred in upper layer circulation. Seasonality is weak and

evident at only a few sites. Circulation patterns and transports have been compared with the NRL Layered Ocean Model (NLOM).

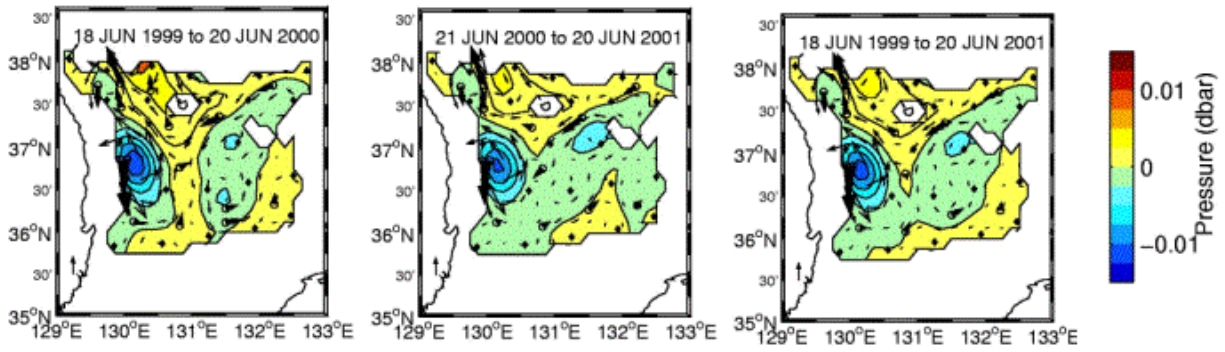

Figure 2. Time-average deep currents and geostrophic pressure fields for year-1, year-2, and the 2-year mean. [Pressure gauge locations at diamonds; current meters at open circles. Bold arrows show measured currents; thin arrows show geostrophic currents; velocity scale in lower left corner indicates 2 cm/s; colorbar indicates residual geostrophic pressure. Note the strong mean cyclonic western-intensified cell, northward outflow over the Korea Plateau, inflow through Ulleung-Dok channel.]

Park and Watts [2002] discuss the response of the southwestern JES to atmospheric pressure P_{atm} and wind stress forcing, which is particularly interesting because of the enclosed nature of the JES basin (Figure 3), with straits connecting to open ocean. Coherence analyses between all the

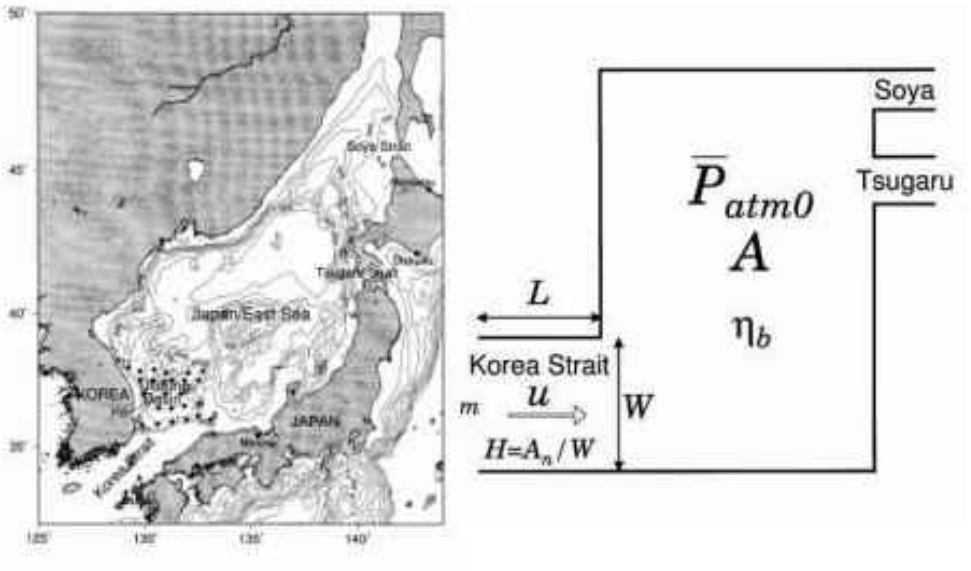

Figure 3. The real JES and a Helmholtz-like idealization, which accounts for geostrophic flow through three straits connected to the open ocean.

P_{bot} measurements reveal that the response of the southwestern JES is nearly uniform at frequencies lower than 0.6 cpd. The Ulleung Basin sea level departs significantly from inverted barometer (IB) response in the frequency band 0.2 to 0.7 cpd. The coherence between P_{atm} and P_{bot} is maximum at 0.2 cpd. P_{atm} produces more significant forcing than does wind stress in this region. A simple Helmholtz-like model (Figure 3) was applied to study the limiting role of the three straits (accounting for rotational geostrophic effects upon flow through them). The resonance frequency predicted by this simple model is near the frequency of maximum coherence between P_{atm} and sea surface height (SSH), both as measured at coastal tide stations and as estimated from P_{bot} by the hydrostatic approximation. Phase relations and response function gains between these variables confirm the applicability of this simple model to the JES for low-frequency bands below the Helmholtz-like resonance frequency. At higher frequencies the response relaxes back toward IB, which suggests the mass field adjusts internally within the JES without substantial exchange through the straits (at high frequencies). The phase relation between the y-component of wind stress and SSH reveals another strait-controlled effect: at high or low frequencies of wind stress forcing, water mass respectively sets up within the UB or exchanges through Korea Strait.

IMPACT/APPLICATIONS

The GEM-MODAS interpretation is being extended and applied to satellite altimeter data collected during the past decade in the JES to estimate subsurface current and temperature structure.

TRANSITIONS

PIESs of this new model, developed in part under this grant, are being applied to studies in the Agulhas, the Kuroshio, and the Gulf of Mexico.

RELATED PROJECTS

The ONR sponsored a group of research projects under a Departmental Research Initiative (DRI) in the Japan/East Sea. The overall web link is http://sam.ucsd.edu/onr_jes/onr_jes.html

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